basis that wind equipment in current use does not have sufficient accuracy reliably to detect small-scale phenomena in the upper troposphere. The microscale feature of clear air turbulence has been found [8] by numerous jet aircraft penetrations to have an average size of less than 50 mi. in length and less than 2000 ft. in depth. In view of these considerations, it is believed more desirable to locate zones of turbulence with reference to a model rather than to unrepresentative wind data of questionable value.

5. CONCLUSIONS

Most of the extreme vertical wind shears computed from rawin data near the core of the jet stream during August 1–2 showed little or no agreement with the jet stream models, lacked continuity, and appeared unrepresentative when compared to surrounding stations. When the wind data were smoothed to remove the unrepresentative features and the vertical shears were averaged over a 20,000-ft. layer, a pattern emerged on the vertical wind shear chart that indicated some prognostic value in planning wind forecasts for jet aircraft. A comparison of the greatest vertical wind shears computed directly from rawin data with those computed from the thermal wind equation and those obtained from the smoothed wind profile is made in table 2. The largest average vertical wind shears were compatible with the jet stream model and were located north of the jet in conjunction with the strongest horizontal wind shears and temperature gradient. Although some errors were undoubtedly introduced in the smoothing process, they were considered insignificant in the broadscale sense.

REFERENCES

1. National Advisory Committee for Aeronautics, "Meteorological Problems Associated with Commercial Turbojet Aircraft Operations," *NACA Research Memorandum* 54L29, Washington, D. C. 1955.
2. R. M. Endlich, S. B. Solot, and H. A. Thur, "The Mean Vertical Structure of the Jet Stream," *Tellus*, vol. 7, No. 3, Aug. 1955, pp. 308–313.
3. H. Riehl et al., "The Jet Stream," *Meteorological Monographs*, vol. 2, No. 7, American Meteorological Society, Boston, Mass., Aug. 1954.
4. N. Dvoskin and N. Sissenwine, "Evaluation of AN/GMD–2 Wind Shear Data for Development of Missile Design Criteria," *Air Force Surveys in Geophysics* No. 99, Air Force Cambridge Research Center, Bedford, Mass., Apr. 1958.
5. H. Riehl, F. A. Berry, and H. Maynard, "Exploration of the Jet Stream by Aircraft during the 1952–1953 Winter," *Journal of Meteorology*, vol. 12, No. 1, Feb. 1955, pp. 26–35.
6. A. Kochanski, "Horizontal Temperature Gradient at 200 mb. and Adjacent Levels," *Bulletin of the American Meteorological Society*, vol. 37, No. 2, Feb. 1956, pp. 47–54.
7. E. R. Reiter, "The Layer of Maximum Wind," *Journal of Meteorology*, vol. 15, No. 1, Feb. 1958, pp. 27–43.
8. R. L. McDougal, T. L. Coleman, P. L. Smith, "The Variation of Atmospheric Turbulence with Altitude and Its Effect on Airplane Gust Loads," NACA RM No. L53G15a, Langley Field, Va., Nov. 9, 1953.

Correspondence

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divergence of the actual flow is replaced by that of the normal, which presumably is in turn a reflection of the large-scale planetary influences mentioned earlier.

Variants of this method, based on recognition that the second term on the right of equation (3) is related to the errors of the barotropic model, have been suggested by Berson [2] and Williams [3].

The relation to Wolff's model may be seen if the basic current is defined to be the sum of the first three harmonics of the actual flow pattern. The analogy becomes more exact if the fictitious changes in the three harmonics are removed at the end of each time-step. Perhaps some difference still remains due to the fact that Wolff's model permits the changes (or tendency) of the three harmonics to be influenced by non-linear interaction with the shorter waves, while this is not permitted when using equation (3).

A method very similar to that of Wolff, but dealing with one-dimensional wave motions, is that proposed by Graham [4].

Another in this family is the present operational model of the Extended Forecast Section, U. S. Weather Bureau, proposed by Namias [5]. Here a "fictitious" wind ($\mathbf{V}_F$) is defined by the equation:

$$\mathbf{V}_F=\mathbf{V}-(\mathbf{V}_B-\mathbf{V}_B^\phi) \tag{4}$$

where $\mathbf{V}$ is the actual wind, $\mathbf{V}_B$ is the basic current at the same point and $\mathbf{V}_B^\phi$ is the latitudinal average, or zonal component of the basic current for the latitude of $\mathbf{V}$. The predictive equation is then obtained by assuming that the absolute vorticity of the fictitious current is conserved:

$$\frac{\partial \zeta_F}{\partial t}=-\mathbf{V}_F\cdot\nabla\eta_F \tag{5}$$

The close correspondence between equations (5) and (3) can be seen by expanding them using the definition of the perturbation current ($\mathbf{V}^*$):

$$\mathbf{V}=\mathbf{V}^*+\mathbf{V}_B \tag{6}$$

In this manner equations (3) and (5) become (7) and (8) respectively:

$$\frac{\partial \zeta^*}{\partial t}=-\mathbf{V}_B\cdot\nabla\zeta^*-\mathbf{V}^*\cdot\nabla(\zeta_B+f)-\mathbf{V}^*\cdot\nabla\zeta^* \tag{7}$$

$$\frac{\partial \zeta^*}{\partial t}=-\mathbf{V}_B^\phi\cdot\nabla\zeta^*-\mathbf{V}^*\cdot\nabla(\zeta_B^\phi+f)-\mathbf{V}^*\cdot\nabla\zeta^* \tag{8}$$

It will be seen that these two equations are identical except that in equation (8) the zonal component of the basic current replaces its value at a point. Physically, the difference appears to be related to the fact that in the Extended Forecast Section's operational model the perturbation is initially uncoupled from the basic current. This appears to prevent any important non-linear exchange of energy between these two currents, while such an exchange is permitted using equation (3).

The normal circulation was first used as the basic current in equation (4), but later it was decided to replace this with a large-scale flow pattern more characteristic of the particular season during which the forecast is prepared. A monthly-mean chart, centered on forecast day, is now used for this purpose. Tests indicate that this results in considerable improvement (Namias, to be published). Although the monthly-mean circulation evolves more rapidly than the normal, this apparently is more than compensated by a reduction in magnitude of the perturbation divergence.

It must be clear that perturbation models such as those described above need not be derived solely by using the approximate vorticity equation (1). For example, the writer is at present working with one of several single-parameter models where a direct estimate is made of the divergence associated with large-scale planetary waves. In this case, equation (1) cannot be used in the perturbation method, and at least one more term must be added, preferably one which expresses some unknown or difficult-to-measure property of the actual flow. This unknown property is then replaced by the corresponding known property of the basic current.

It is believed that this procedure has the advantage that the models are constrained to behave in a fashion consistent with the observed behavior of the general circulation, because in essence the errors of any model are replaced by estimates based on experience. It is also felt that this procedure may lead to a better physical understanding of the circulation. In this connection it may be noted that the success of Wolff's model, which makes use of the observed stationary character of long waves, stimulated the successful search for a new operational model which contains a more satisfactory physical basis for this characteristic [6]. This new model is based on the theoretical work of Rossby [7]. Another important theoretical paper which treats the special problem of planetary waves is that of Burger [8]. Perhaps a more general formulation of the empirical approach, together with these theoretical studies, can lead to a practical solution of the preferred geographical locations and observed motions of the long waves.

REFERENCES

1. P. F. Clapp, "Application of Barotropic Tendency Equation to Medium-Range Forecasting," *Tellus*, vol. 5, No. 1, Feb. 1953, pp. 80–94.
2. F. A. Berson, "A Quantitative Analysis of Large-Scale Flow Patterns with Special Regard to the Effect of Eddy Motion," *Quarterly Journal of the Royal Meteorological Society*, vol. 79, No. 340, Apr. 1953, pp. 210–223.
3. S. Williams, "An Empirical Correction to the Barotropic Forecast," *Tellus*, vol. 10, No. 2, May 1958, pp. 216–224.
4. R. D. Graham, "An Empirical Study of Planetary Waves by Means of Harmonic Analysis," *Journal of Meteorology*, vol. 12, No. 4, Aug. 1955, pp. 298–307.
5. J. Namias, "Progress in Objectivization and Automation of Extended Forecasting," *Transactions of the New York Academy of Sciences*, Series II, vol. 19, No. 6, Apr. 1957, pp. 581–592.
6. G. P. Cressman, "Barotropic Divergence and Very Long Atmospheric Waves," *Monthly Weather Review*, vol. 86, No. 8, Aug. 1958, pp. 293–297.
7. C.-G. Rossby and collaborators, "Relation Between Variations in the Intensity of the Zonal Circulation of the Atmosphere and the Displacements of the Semi-Permanent Centers of Action," *Journal of Marine Research*, vol. 2, No. 1, 1939, pp. 38–55.
8. A. P. Burger, "Scale Consideration of Planetary Motions of the Atmosphere," *Tellus*, vol. 10, No. 2, May 1958, pp. 195–205.

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